Experimental characterization and Monte Carlo simulation of Si(Li) detector efficiency by radioactive sources and PIXE

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Abstract

The intrinsic efficiency of a Si(Li) X-ray detector was simulated using the Monte Carlo codes MCNP and GEANT and determined experimentally with radioactive sources and PIXE data. Excellent agreement between simulations and measurements was obtained.

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Menu…

1. Few words about detector efficiency…
2. Methods: what have we performed?
3. Results: surprising results !!!!

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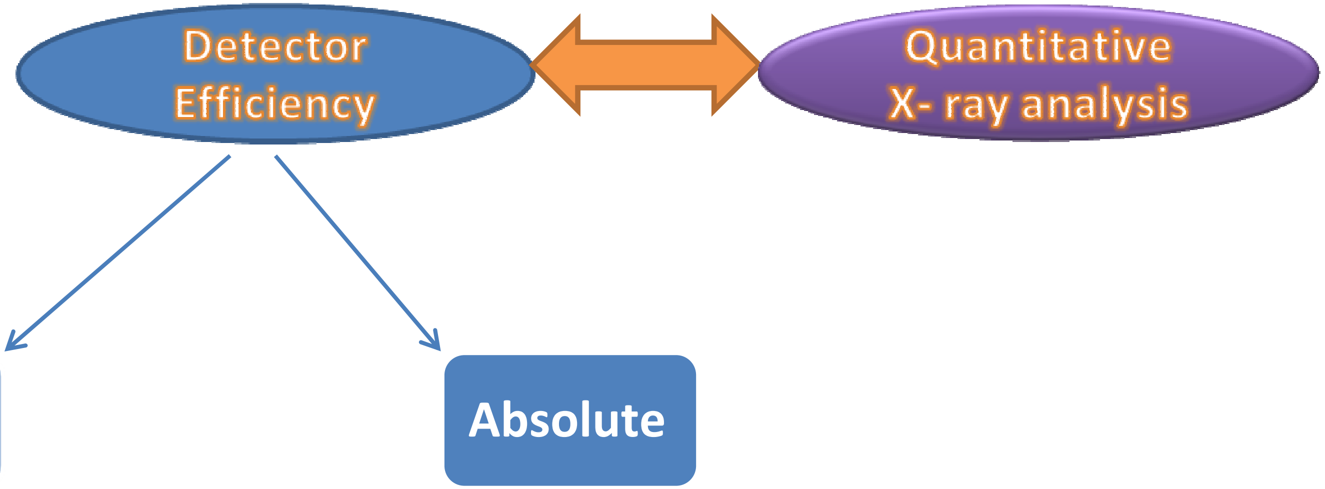
1. Introduction



- ✓**Cristal dimensions ;**
- ✓**Photon energy ;**
- ✓**thickness of the Be/Au absorber layer**

- ✓**Solid angle;**
- ✓**Intrinsic efficiency x solid angle**

When recently needing the efficiency of a new Si(Li) detector, we decided to **simulate the efficiencies with the Monte Carlo codes MCNP and GEANT** (Zamburlini et al., 2007; Karamanis 2003) and to compare the calculations with experimental data obtained with radioactive sources and PIXE measurements.

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2. Methods

2.1. Intrinsic efficiency –energy relationship

The intrinsic efficiency as a function of X-ray energy is **(Hansen et al., 1973):**

$$\varepsilon(E) = T(E) \times A(E) \times (1 - P_{esc})$$

T(E) : transmittance of the successive absorbing layers (Be window and Au :),
A(E) describes the absorption of photons in the sensitive volume of the detector,
$P_{esc}(E)$ is the probability of Si K X-ray escape events (< 2.5%, taken here to be negligible).

The transmission and absorption factors are expressed as follows:

$$T(E) = \exp\left[-\sum_{layers} \mu_l \cdot x_l\right] \quad (2)$$

$$A(E) = 1 - \exp(-\tau_{Si} \cdot x_{Si}) \quad (3)$$

μ_l are the total X-ray mass attenuation coefficients, x_l are the layer thicknesses of the corresponding materials, τ_{Si} is the photoabsorption coefficient and x_{Si} is the detector thickness. Mass attenuation coefficients were calculated by the ***XMUDAT*** computer program (IAEA).

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2. Methods

2.2. Measurements with radioactive sources

Spectra of ^{241}Am, ^{137}Cs, ^{133}Ba and ^{55}Fe standard sources were measured in air on the detector axis at varying distances from the detector's front face.

Source	*Activity (Bq)*	*Energy (keV)*	*Branching (%)*
^{241}Am[a]	(4.22 ± 0.21) 10^5	13.95; 17.75; 20.78; 26.34; 59.5	11.88; 11.6; 0.0284; 2.40; 35.9
^{55}Fe[b]	(1.20 ± 0.11) 10^9	5.88; 5.90; 6.49	8.5; 16.9; 2.99
^{137}Cs[b]	(1.88 ± 0.08) 10^5	31.82; 32.19; 36.30; 36.38; 37.25	2.04; 3.76; 0.35; 0.68; 0.21
^{133}Ba[b]	(4.46 ± 0.22) 10^4	30.62; 30.97; 34.92; 34.99; 35.82	34.9; 64.5; 5.99;11.6; 3.58

Table 1: X- and γ-ray data used for the measurements with the radioactive sources

[a]X-ray data from Lépy et al. 1994. Data on the 26.4 and 59.5 keV γ-rays from Firestone and Ekström, 1999;

[b]X-ray data from Firestone and Ekström, 1999

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2. Methods

2.3. PIXE Measurements

The PIXE experiment was performed at the ***InESS*** Laboratory of Strasbourg :

- ✓ 2 MeV protons;
- ✓ Beam current was in the 10-100 nA.

The PIXE targets were prepared on 1.5 µm Mylar backings from three slightly acidified solutions A, B and C (Table 2) by nebulization (Jolly and White, 1971).

	Compound	Cation (µg/g solution)
Solution A	$Ba(NO_3)_2$	682.2 ± 9.6
	$Cd(NO_3)_2.4H_2O$	483.6 ± 9.7
	$Fe(NO_3)_3.9H_2O$	133.3 ± 2.4
	$Ni(NO_3)_2.6H_2O$	224.9 ± 1.3
	$Pb(NO_3)_2$	822.1 ± 35.7
	$Sr(NO_3)_2$	416.6 ± 1.5
	NaCl	729.3 ± 10.5
Solution B	KNO_3	452.1 ± 9.0
	$Cr(NO_3)_3.9H_2O$	121.4 ± 2.6
	$Fe(NO_3)_3.9H_2O$	156.2 ± 1.8
	$Zn(NO_3)_2.4H2O$	230.8 ± 6.2
	$Sr(NO_3)_2$	560.7 ± 4.1
Solution C	NaCl	1570.4 ± 228.1
	$Zn(NO_3)_2.4H_2O$	1295.4 ± 17.9
	$Pb(NO_3)_2$	397.8 ± 16.3

Table 2: Composition of the solutions used for PIXE targets.

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2.3. PIXE Measurements

In the case of a thin sample, the absolute detector efficiency at the line *k* of element *j* is (Johansson and Campbell, 1988):

$$\varepsilon(E_{jk}) = \frac{Y_{jk}}{n_p C_j \sigma_j W_{jk}} \times \frac{4\pi}{\Omega}$$

E_{jk} is the energy of the line k of element j,
n_p is the number of protons on the target,
C_j is the concentration of element j,
Y_{jk} is the yield of line k of element j,
σ_j is the ionization cross section for the protons,
W_{jk} is the K- or L-shell fluorescence yield for line k, and
Ω is the solid angle of detection.

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2.3. Monte Carlo simulations: MCNP and GEANT

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- **MCNP 4C (Briesmeister, 2000)** is suitable for modeling the detector response, since it contains a special tally, F8, which is specific for pulse height determination, i.e. energy deposited in the detector.

- In **GEANT4**, the efficiency was calculated as th ratio of number of photons contributing to the histogram of a spectral line to the total number of histories.

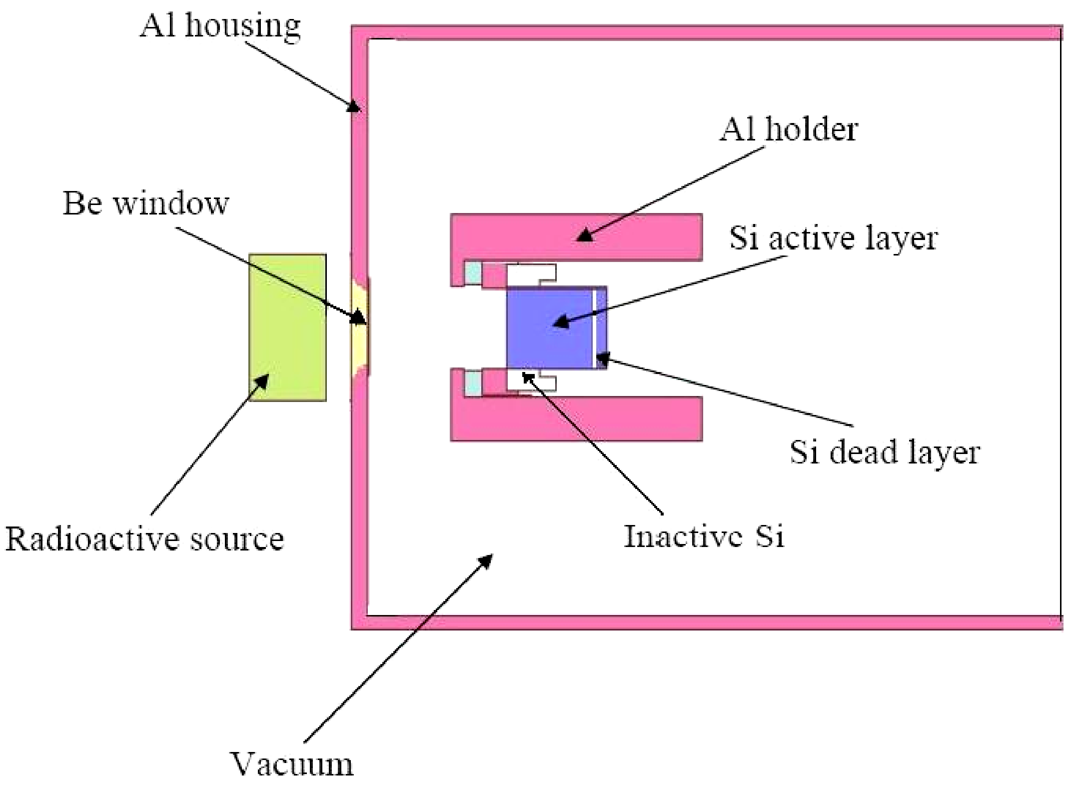

Fig. 1. Schematic representation of the configuration used to model the response of the Si(Li) detector with MCNP and GEANT.

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3. Results

3.1. Modeling the detector

. An example of the inconsistencies between simulated and measured data, as mentioned briefly in the Introduction, are the two ^{241}Am spectra shown in Fig. 2(a) for a source-detector distance of 6 cm. The discrepancy is quite obvious.

•It was found that the diode dimensions were different from the specifications and in addition that the diode was positioned slightly off axis behind the Be window.

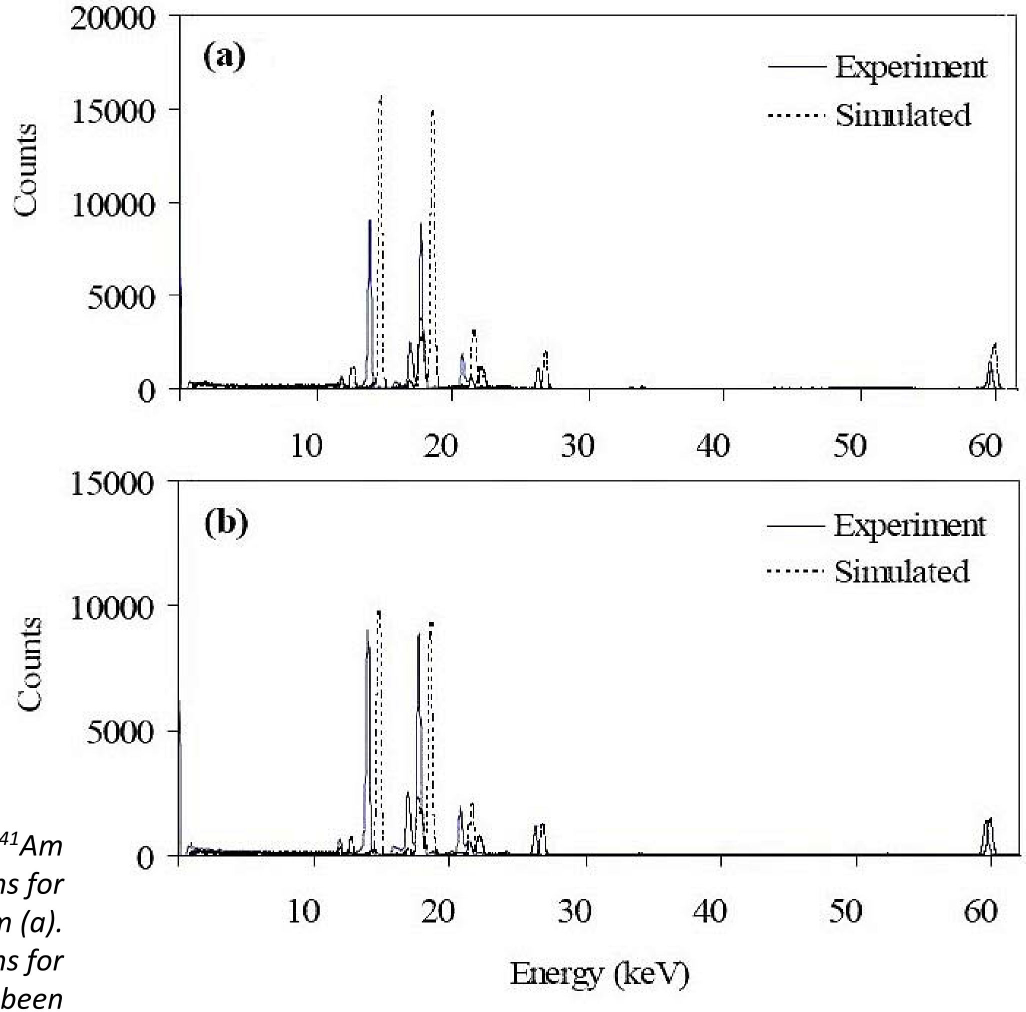

Fig. 2. Comparison of the MCNP-simulated ^{241}Am spectrum, using the manufacturer's specifications for the Si(Li) crystal, with the measured spectrum (a). Same comparison using the new crystal dimensions for the simulation (b). The measured spectra have been shifted to the left by about 2 keV for better visualization.

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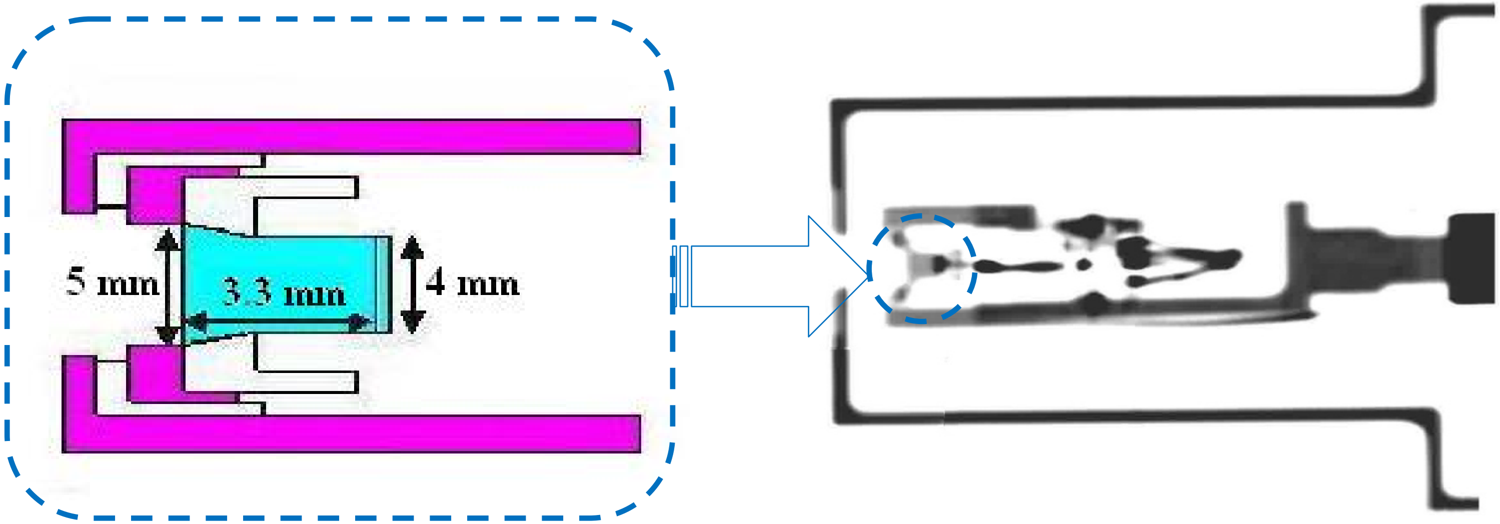

Fig. 3. Medial slice of an X-ray radiographic scan of the Si(Li) detector inside its cryostat **(right)** and corresponding Si(Li) configuration for the simulations **(left).**

3. Results

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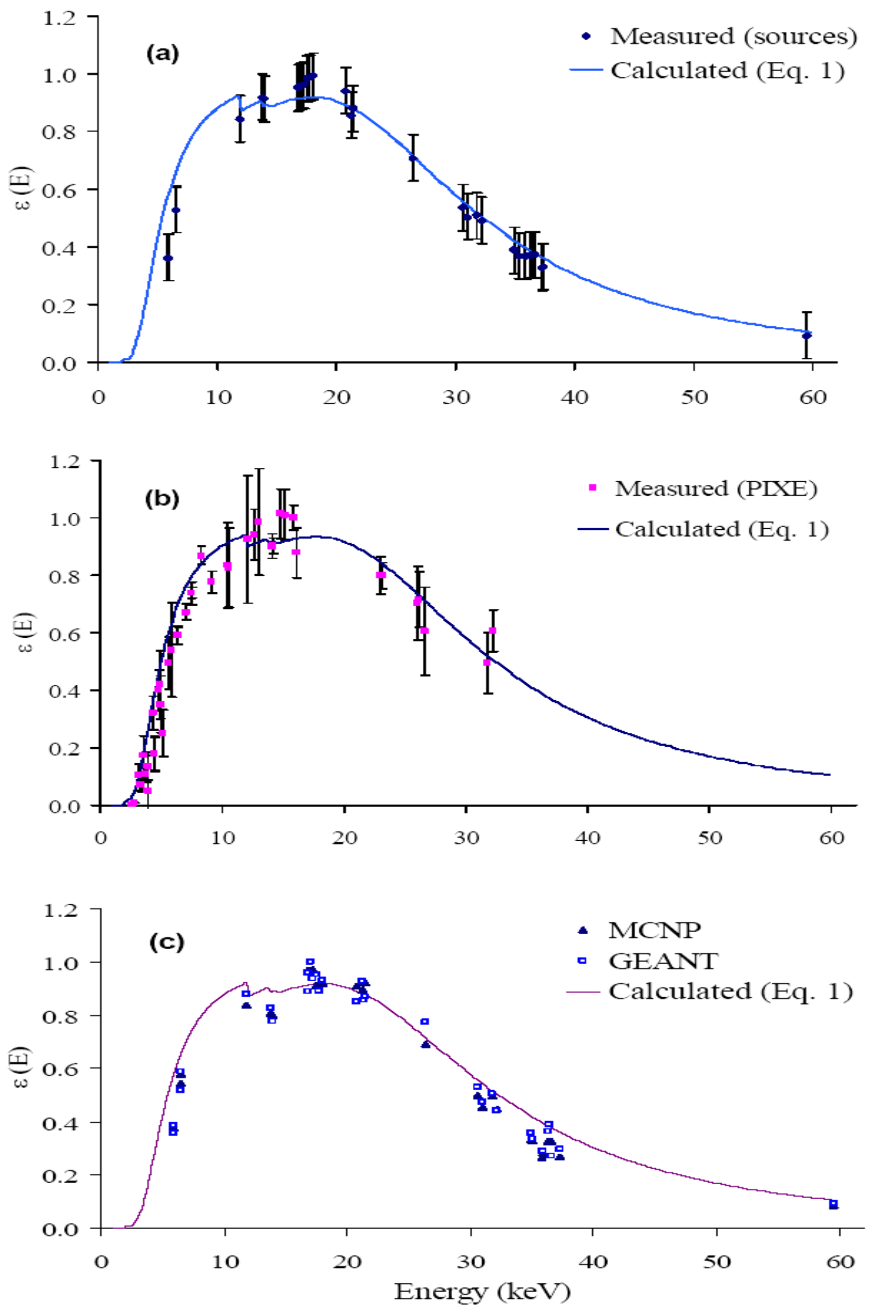

Fig. 4. Experimental and simulated efficiencies e(E) of the Si(Li) detector. Data measured with radioactive sources are compared to the curve of Eq. (1) in (a); Efficiency from PIXE data compared to curve of Eq. (1) is shown in (b); Simulated efficiencies and curve of Eq. (1) are shown in (c).

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Conclusion

Now that we have a good estimation of the Si(Li) intrinsic efficiency and some experience in manipulating MCNP and GEANT, the next steps towards setting up a quantitative XRF system in the laboratory can be undertaken…

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The End……begin…….here!!!

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